DOCUMENT RESUME

ED 138 968 CS 003 484

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TITLE Orthographic Regularity, Positional Frequency, and Visual Processing of Letter Strings. Report No. 413.
INSTITUTION Wisconsin Univ., Madison. Research and Development Center for Cognitive Learning.
SPONS AGENCY National Inst. of Education (DHEW), Washington, D.C.
PUB DATE Apr 77
CONTRACT NE-C-00-3-0065
NOTE 68p.

EDRS PRICE MF-$0.83 HC-$3.50 Plus Postage.
DESCRIPTORS *Character Recognition; College Students; Grade 6; Letters (Alphabet); *Orthographic Symbols; Reaction Time; *Reading Processes; *Reading Research; *Visual Perception

ABSTRACT

The studies reported here examined the role of orthographic regularity and summed positional frequency in the perception of letter strings. College sophomores and sixth graders were asked to indicate whether or not a target letter was present in a six-letter string. Orthographic regularity and summed positional frequency were found to have no effect on reaction time. In contrast, the number of letters in the catch string that were physically similar to the target letter had a large effect on reaction time. In another experiment, the letter string was presented for a period of short duration, followed immediately by a masking stimulus and then by the target letter. College readers indicated whether or not the target was present in the test string. Accuracy of performance was critically dependent on the orthographic regularity and summed positional frequencies of the letters in the test string. No effect of letter similarity was observed. The large differences that were observed between these two tasks can be accounted for in terms of the stages of processing that are critical for performance in the tasks. (Author/AA)

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Technical Report No. 413

ORTHOGRAPHIC REGULARITY, POSITIONAL FREQUENCY, AND VISUAL PROCESSING OF LETTER STRINGS

by

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Report from the Project on
Conditions of School Learning and
Instructional Strategies

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April 1977

CS003 884

Published by the Wisconsin Research and Development Center for Cognitive Learning, supported in part as a research and development center by funds from the National Institute of Education, Department of Health, Education, and Welfare. The opinions expressed herein do not necessarily reflect the position or policy of the National Institute of Education and no official endorsement by that agency should be inferred.

Center Contract No. NE-C-00-3-0065

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The Wisconsin R&D Center is supported with funds from the National Institute of Education; the Bureau of Education for the Handicapped, U.S. Office of Education; and the University of Wisconsin.

Orthographic Regularity, Positional Frequency, and Visual Processing of Letter Strings

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The processes by which words are recognized during reading have concerned psychologists and educators for almost a century. From Huey (1908/1968) to Gibson and Levin (1975) every major treatise on reading has discussed this issue at length, but generally concluded, as did Huey (1908/1968, p.102) that "It is very difficult to draw final conclusions concerning visual perception in reading. . ." Word recognition forms a bridge between visual information processing skills and comprehension, and is therefore important for understanding how the two relate to each other. On the one hand, rapid word recognition is the goal of all decoding instruction and may, as suggested by Venezky and Massaro (1976, in press) be the only major new skill which a child must acquire in learning to read. On the other hand, visual recognition of words and the attachment of meanings to them forms the starting point for comprehension processes. Although the relationship of

lexical competence to reading comprehension remains to be explored, the extremely high correlations between vocabulary and comprehension components of standardized reading tests across all the elementary grades suggest that more thorough investigation is warranted.

Good and poor readers have been shown to differ in performance on a variety of general tasks, but until recently little attempt has been made to explore how children of different reading abilities might differ in basic word recognition processes. If good and poor readers utilize the same processes, but differ in speed or accuracy, then remediation methods based on common approaches to reading instruction would be warranted. However, if fundamental differences in visual recognition processes are found, then totally different remedial methods would be required. The rationale for the present research is that basic word recognition processes, when defined for competent adult readers, can be used to assess word recognition abilities of good and poor readers at the elementary level.

A model for visual processing

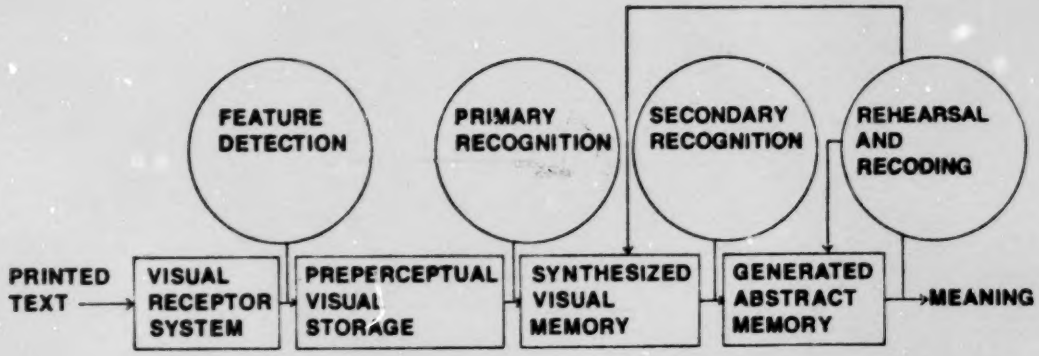
The conceptual framework for the present research derives from an information-processing stage model (Massaro, 1975a,c). Although this model has received considerable support from a wide variety of information-processing tasks,

our purpose in presenting the model here is not to justify it over other models, but to provide a precise framework for both the theoretical hypotheses and the experimental tests of the current research. The major contribution of the stage model is that it resolves a wide variety of superficially conflicting results. If we account for the stages of processing in the experimental task and how various independent variables influence each of these stages, the research on letter-string recognition significantly reduces our uncertainty about the nature of visual processing in reading.

In the current model, a segment of text is registered as a light pattern on the retina which stimulates the visual receptors. The first process, called feature detection, detects basic letter features which are transmitted to preperceptual visual storage (cf. Figure 1). The feature detection process takes time and it is assumed that the different features require different times for detection. For example, the general circular shape of the letters c and o may be detected before information about whether or not a gap is present. As the visual features enter preperceptual visual storage, the primary recognition process attempts to synthesize these isolated features into a sequence of

FLOW DIAGRAM OF PROCESSING PRINTED TEXT

Figure 1



letters and spaces in synthesized visual memory. To do this, the primary recognition process can utilize information held in long-term memory. For the accomplished reader this includes a list of features for each letter of the alphabet along with information about the orthographic

structure of the language. The primary recognition process utilizes both visual features and the information about orthographic structure of the language in its synthesis of the letter string.

The primary recognition process operates on a number of letters in parallel. The visual features read out at each spatial location define a set of possible letters for that position. The recognition process chooses from this candidate set the letter alternative which has the best correspondence in terms of visual features. However, the selection of a `best' correspondence can be facilitated by knowledge of orthographic structure. If for example, an th-m has been resolved in a letter string, and the features available for the third letter match either c or e, the reader might accept e without waiting for further visual information, since thcm is irregular while them is not. The primary recognition process, therefore, attempts to utilize both the visual information in preperceptual storage and knowledge about the structure of legal letter strings.

The primary recognition process transmits a sequence of recognized letters to synthesized visual memory. The secondary recognition process transforms this synthesized visual percept into a meaningful form in generated abstract memory. The secondary recognition process makes this transformation by finding the best match between the letter

string and a word in the long-term lexicon. Generated abstract memory corresponds to the short-term or working memory of most information processing models. In our model, this memory is common to both speech perception and reading. Recoding and rehearsal processes build and maintain semantic and syntactic structures at the level of generated abstract memory. The reader is referred to Massaro (1976b) and Venezky and Massaro (1976) for a more complete description of the model.

Orthographic regularity and primary recognition

There is considerable experimental evidence that the reader's knowledge about orthographic structure influences the primary recognition of letter strings (for reviews, see Massaro, 1975b and Venezky & Massaro, 1976, in press). Most of the evidence comes from a visual recognition paradigm initiated by Reicher (1969). In this task, a single letter or a letter-string is presented for a short period, followed by a visual masking stimulus. The subject is then given two alternative letters and indicates which of the alternative letters was presented at an indicated position in the display. The alternatives are selected to eliminate the possibility of a guessing advantage for highly constrained letter strings. For example, if the subject was shown the display WORD, the alternatives would be ---$\frac{D}{K}$. In this case,

knowing that the display was a word and that WOR occurred in the first three positions would not be sufficient information for the subject to choose between D and K in the fourth position since both alternatives spell words. Performance on this trial would be compared to a letter trial in which D would be presented without context followed by the alternatives $\frac{D}{K}$, and a nonword trial in which ORWD would be presented followed by the alternatives ---$\frac{D}{K}$. When Reicher initiated the paradigm, he found a 10% advantage for words over nonwords and single letters. This basic result has been replicated by Wheeler (1970), Johnston and McClelland (1973), and Thompson and Massaro (1973).

The same advantage has been found with pseudowords, which are spelled like English words but have no meaning (Aderman & Smith, 1971; Baron & Thurston, 1973). This latter result shows that orthographic structure is sufficient and semantic meaning is not necessary for the "word" advantage (cf. Venezky & Massaro, 1976, in press). (For example, consider the case in which the subject is given the lowercase string coig and has resolved just the circular envelope of the first letter and all of the last three letters. Given that c, e, and o are the only letters that are consistent with the circular envelope, these are the only letters possible at this position. If the reader further assumes that the string must conform to English

orthography, however, only c is possible since the strings ooig and eoig are illegal. Therefore, the reader can synthesize coig since it is the only valid alternative. Given the nonword string cgoi, on the other hand, no unambiguous choice can be made between c, e, and o for the first letter. Accordingly, the reader is equally likely to synthesize any of the three letters and will be correct only one out of three times.) In terms of our model, these results demonstrate that familiarity with the orthographic structure of words facilitates primary recognition of their letters relative to the nonword or single-letter cases.

There is also evidence that orthographic regularity can facilitate search for a target letter in a sequence of test letters. Krueger (1970a) presented subjects with a target letter followed by a display of 25 six-letter words or 25 six-letter nonwords. The nonwords were formed by randomly permuting the letters at each serial position in the words. Search time was about 100 msec/word or 20% faster through word than nonword displays. In another experiment, Krueger looked at relative search times for common and rare words and third order pseudowords. Subjects saw a target letter followed by a display of two six-letter strings. Given an average reaction time of 1000 msec, search time was 36 msec faster for common than for rare words while rare words were 48 msec faster than the third-order pseudowords. The

pseudowords were in turn 28 msec faster than the nonword strings. In a final study, highly practiced subjects searched for 1, 2, or 3 target letters in word and nonword displays of two six-letter strings. Search time was a linear increasing function of the number of target letters and was faster for word than nonword displays. More importantly, these two effects were additive, indicating that the word-nonword difference was affecting overall search time at a different processing stage than the effect of the number of target letters. It is commonly assumed that the number of target letters influences memory comparison, so that the advantage of the word strings appears to occur at the recognition stage of processing.

In a second series of experiments, Krueger (1970b) had subjects search for a target letter in a single six-letter word or nonword string. The target letter was presented before (visual search), after (memory search) or simultaneously with the test string. The subjects responded about 9% faster for words than nonwords when the target was presented after the display and about 5% faster when the target letter was presented before the display. In the simultaneous presentation, the target letter was centered immediately above the test string or was repeated above each letter in the test string. A 4% word advantage occurred in both paradigms. The only condition that eliminated the word

advantage was one in which the letters in the string were arrayed vertically rather than in their standard horizontal arrangement. Krueger's (1970a,b) results offer substantial support for the utilization of orthographic structure in searching for a target letter in test strings. Krueger, Keen, & Rublevich (1974) asked adults and fourth-grade readers to search for a target letter in a list of five six-letter words or nonwords. Reaction times were about 10% faster for the words than nonwords and about 3% faster for (third-order) psuedowords than nonwords. These effects did not vary with reading ability.

James and Smith (1970) and Gibson, Tenney, Barron, and Zaslow (1972) failed to find faster search times through pseudowords than nonwords, but Krueger (1975) has argued that these null effects may be due to the utilization of a less sensitive between-subjects design. Gibson et al. (1972) pointed out, however, that their subjects did not have to recognize each of the test letters but could make decisions on the basis of letter features alone. This strategy was possible because the same target letter was used on all trials. Extended and specific practice with a single target should encourage a feature search strategy. Krueger on the other hand has consistently employed different target letters on each trial. It remains to be

seen whether any specific procedural difference can account for the conflicting experimental results.

More recently, Mason (1975) carried out a series of experiments with school children that evaluated the influence of orthographic structure in a letter search task. Good and poor sixth-grade readers indicated whether or not a six-letter string contained a predetermined target letter. The letter strings were words or nonwords and the nonwords differed in the degree of orthographic structure as defined by positional frequency.[1] (The positional frequency of a given letter in a letter string is measured by the frequency with which the letter occurs in the same spatial position in words of the same length. The positional frequency of a letter string is the sum of the positional frequencies of each of the individual letters in the string. The positional frequencies were computed from the tables of Mayzner and Tresselt (1965) which gave the total number of occurrences of each letter at each spatial position in a sample of 20,000 words of running text.) Faster search times in the strings with high positional frequencies would support the hypothesis that these letters are recognized in a shorter time than the letters in the strings with low

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[1] The phrase `positional frequency' is used here in place of what Mason (1975) labels `spatial frequency'.

positional frequencies. Mason (Experiment II) found that good readers were faster (on both yes and no trials) for strings with high than with low positional frequencies. Poor readers showed no difference. The results support the idea that the time to resolve (recognize) the letters in a string is influenced by the likelihood of letters occurring in their more common spatial positions.

Our research is directed at what we believe to be two limitations in the generality of Krueger's and Mason's (1975) findings. The first question is to what extent can the target-search task be expected to be sensitive to the orthographic structure of letter-strings? The second is how well does summed positional frequency capture the reader's actual knowledge and utilization of orthographic structure in visual recognition? We consider each of these questions in turn.

Target-search and orthographic structure

In the target-search task, the reader is given a target letter followed by a letter string and indicates by "yes" or "no" responses whether or not the letter-string contained the target letter. The influence of orthographic structure on performance in the target-search task depends on whether the subject is capable of responding at the level of letter features (i.e., at the feature detection stage) or whole

letters (i.e., after the primary recognition stage). If primary recognition must be completed before a decision can be made, we predict a positive effect of orthographic structure in the task, whereas no influence of orthographic structure is predicted if a decision can be initiated at the level of feature detection. At first glance, we might expect that primary recognition must be completed before a decision can be made in the search task. There is some evidence, however, that readers do not have to recognize all of the letters in the test letter string to perform the target search task (Estes, 1975; Massaro & Klitzke, in press). Consider the case in which the subject is looking for the target letter b in the letter strings cose, peom, deom, and delm, respectively. In all cases, the answer is no but the subject may be able to decide on this answer faster with some of the strings than with others. We assume that recognition of the string is a temporally extended process and that some letters' features are resolved before others. There is some evidence that overall letter shape can be resolved and made available to later stages of processing before the letter is completely recognized (Bouma, 1971; Massaro & Schmuller, 1975). If this were the case, a subject might be able to respond "no" to the first two example strings very quickly since none of the letters has the same overall ascender shape as the target letter.

In contrast, the third and fourth strings will require additional processing time. Other features of the ascending letters of these strings must be resolved to distinguish these letters from the target letter. Accordingly, we might expect that the time to say no will be longest for the string with two ascenders, intermediate for the string with one ascender, and shortest for the strings with no ascenders. If subjects are utilizing this processing strategy, then we would not expect the orthographic structure of the letter string to influence response time; we should expect rather an influence due to the number of letters similar to the target letter. Given that this processing strategy may not be utilized by younger readers, they may show a smaller effect of letter similarity and a larger effect of orthographic structure.

It should be pointed out that for this model the number of letters in the test string of the same overall shape as the target should not be important on target trials. On these trials, the target letter must be completely resolved before a "yes" response can be made. Therefore, the critical variable on target trials is how quickly the target is recognized rather than the number of letters in the test string that have the same overall shape as the target.

Our analysis of the target search task leads to the expectation that specific practice in the task should be

critical for the results. With very little practice in the task, we might expect the readers to process a letter string through the stage of primary recognition before a decision is made. With practice, however, subjects may begin to make decisions at the level of feature detection and respond before primary recognition is completed. Accordingly, subjects with a small amount of practice might show effects of orthographic structure but no effects of similarity between the target and test letters. With practice, however, the influence of orthographic structure should be attenuated and the similarity between the target letter and the number of letters in the test string should be critical.

Mason (1975) acknowledged this role of practice in her experiments. In Experiment II, subjects were tested for a total of 72 trials after just 5 practice trials and a large effect of positional frequency was observed. Good readers were 43 msec faster on target trials and 120 msec faster on catch trials for letter strings of high positional frequency than for letter strings of low positional frequency. In the next experiment, subjects were given about 100 practice trials before the experiment proper. The average advantage of processing high positional frequency strings was reduced to 23 msec for the good readers. Mason concluded that "good readers were able with intensive practice either to adopt a strategy based on the most salient features of the target

letter, which permitted them to perform the search task more economically on catch trials, or to reject the target letter on a more efficient basis which required less processing of the display letters [p.160]." In our model, practice allows the subjects to make a decision at the level of feature detection before orthographic regularity can influence recognition, thus eliminating a regularity effect on performance.

Positional frequency and orthographic structure

The second question of generality that we address is how well summed positional frequency counts describe a psychologically relevant measure of intra-word redundancy. Although this measure appears to account for the recognition times in Mason's study, we do not believe it is the critical variable that defines the reader's knowledge of orthographic structure. Consider some of the permutations of the letters that make up the word PERSON, which has a summed positional frequency of 1,141. The string PORNES contains the same letters in different positions and has a count of 1,858. The string ENSRPO has a count of 383. Looking at these nonwords, we see that PORNES is spelled like an English word and should be relatively easy to recognize, whereas ENSRPO violates what we know about English spelling and should be relatively difficult to recognize on other than a feature

detection level. However, it is not difficult to find exceptions to the rule. Table 1 lists some letter strings used by Mason whose letters have been rearranged to yield strings with almost equal positional frequencies, but with differing orthographic regularities. It is not possible to determine from Mason's results alone whether differences in positional frequency are fortuitous effects of orthographic regularity as defined by graphemic rules, or if both were responsible for her results.

The present series of experiments addresses the question posed in the preceding discussion. To evaluate the degree to which summed positional frequency is a psychologically relevant measure of intra-word redundancy, we selected letter strings that were high or low on this dimension, and then chose strings in both of these categories which were also orthographically regular or irregular, according to an extension of the rules proposed by Venezky and Massaro (1976, in press). If summed positional frequency is a sufficient description of intra-word redundancy, it should facilitate performance equally well in the regular and irregular strings. Given the word *really*, the permutations *leraly* and *lrlaey* are both high in summed positional frequency but the first string is orthographically regular whereas the second is not. The strings *lyeral* and *ylelra* are the analogous regular and

irregular low frequency strings. These strings were employed as test items in the target search task. If positional frequency is a sufficient description of word structure, the advantage in processing high versus low strings should be the same regardless of their regularity.

Practice effects were assessed in the target search task by testing subjects across four experimental sessions. If practice is critical in the task, we should find reduced effects of orthographic structure along with increased effects of the similarity of the target letter and the letters in the test strings on catch trials.

To evaluate these hypotheses at two levels of reading development, both adult readers and sixth graders were tested. This dichotomy resulted in a weak comparison, however, since about 80% of the sixth graders who volunteered for the experiment were reading at a high school level.

Experiment 1

Method

Subjects. Eleven adult subjects who responded to an advertisement posted in the university community participated an hour a day for two consecutive days. Each subject was paid $4 at the end of the experiment.

Stimulus lists. The stimulus lists were generated from the most frequent 150 six-letter English words in Kucera and Francis (1967). A computer program generated all 720 permutations of the six letters in each word, and computed the summed positional frequency for each permutation from Mayzner and Tresselt's (1965) counts for the absolute frequency of occurrence of single letters at each position in six-letter words. The program listed the 30 permutations with the highest summed positional frequencies and the 30 permutations with the lowest summed positional frequencies. From these lists one orthographically regular and one orthographically irregular item was chosen from the items with the highest summed positional frequency. A similar pair of items was chosen from the items that ranked lowest in summed positional frequency. Due to the difficulty of finding orthographically regular items in the low positional frequency group, all of the original 150 words could not be used. The four different types of items could be generated

from 80 of the words, giving a total of 320 stimulus items in the experiment. The Appendix lists the words, the four permutations that were used in the experiment, and the summed positional frequency of each permutation.

Procedure. The stimulus list of 320 items was divided in half so that the permutations of 40 of the words were in one list and the permutations of the other 40 words were in the other. List One had no repeated letters in 37 of the strings and one repeated letter in 3 of the strings. List Two had at least one repeated letter in each of the 40 strings (cf. Appendix). In the experiment proper, each subject was tested on List One in the first session and List Two in the second session each day. Each letter-string appeared once as a target trial and once as a catch trial. On target trials, the target letter was selected randomly with replacement from the six letters in the test string. On catch trials, the target letter was selected from the remainder of the alphabet which were not members of the test string. The probability of selecting a given target letter on catch trials was weighted by the frequency of occurrence of that letter in all of the 320 test strings. This restriction insured that any given target letter's probability of occurrence was equal for target and catch trials. But this did not ensure that the same letters were

tested in the same positions in both target and catch trials.

On the first day, the subject was introduced to the visual display and the response panel. To acquaint subjects with the response procedure, they were first given 50 trials of responding "yes" and "no" to the words "yes" and "no" presented on the visual display. The word remained on until the subject pressed one of the two buttons. Next, the subject was asked to indicate whether or not a target letter was present in six-letter strings. These practice strings were completely random strings of letters. Each trial began with a 400 msec presentation of the target letter followed by a 400 msec blank period and then the test letter string. The letter string remained on until the subject pressed one of the two buttons. The interval from the response to the onset of the next trial was 1.5 sec. The subject was instructed to respond "yes" if the target letter appeared at least once in the letter string and "no" otherwise. The subject was also instructed to respond as accurately and quickly as possible. Feedback was given at the end of each practice sequence in an attempt to maintain an error rate of about 3%. This practice session was followed by 320 trials of the experiment proper. After a rest of about 10 minutes the subject was given a second testing session consisting of 50 practice trials followed by 320 experimental trials. On

Day 2 the subject also had 2 sessions, each with 50 practice trials followed by 320 experimental trials. A 10-minute rest break was given between sessions.

Apparatus. The displays were presented on a specially modified Beehive video computer terminal under the control of a Harris DC6024/5 computer. A hardware modification permitted the terminal's video to be turned on and off with program-generated control signals. The display strings were loaded into the memory buffer of the terminal with video off and then the video was turned on for the appropriate exposure duration. The Beehive employs a P4, blue-white phosphor which has a nominal decay time to .1% of maximum luminance after 32 msec. The experiment was conducted in a partially darkened room to enhance image contrast and reduce glare on the screen.

All single-letter and letter-string displays were presented in lower case letters. The Beehive uses a 5 by 7 dot matrix, 2.5mm wide by 5mm high. At the average subject viewing distance of approximately 38 cm, the six-letter strings subtended a horizontal visual angle of 2.25° and a vertical visual angle of .60°. The displays were presented in the upper center of the screen. The single-letter target was positioned to appear two lines above serial position three of the string display, a vertical visual angle separation of 1.65°. Reaction times were measured from the

time the video was turned on for the letter string displays. A one KHz clock provided RT measurements accurate to within one msec.

Data analysis. Each subject was tested for a total of 1280 trials in the experiment proper, giving roughly 320 observations per subject in each of the 4 experimental conditions. Error trials were not included in the reaction time analysis.

Results

An analysis of variance was carried out on the mean correct RTs for the 11 subjects with the four sessions and the two levels of positional frequency, orthographic regularity, and test type (target vs. catch trial) as factors. Table 2 presents the mean RTs for target and catch trials as a function of positional frequency and orthographic regularity. Reaction times averaged 16 msec longer for low than for high positional frequency, $F(1,10) = 16.64$, $p < .005$. Responses were 9 msec faster for orthographically regular than for orthographically irregular strings, $F(1,10) = 6.91$, $p < .05$. Catch trials produced RTs that were 78 msec slower than RTs on target trials, $F(1,10) = 15.95$, $p < .005$. Reaction times decreased from 708 msec in session 1 to 639 msec in session 4, but this effect was not statistically significant, $F(3,30) = 1.72$, $p > .1$.

Also, sessions did not interact with any of the other variables. No other source of variance approached significance in the analysis.

A second analysis was carried out to evaluate whether the RTs on catch trials were sensitive to the similarity between the target letters and the letters in the catch string. To do this, the letters of the alphabet were classified into three types: x-height, ascenders, and descenders. The relationship between each target letter and catch string was defined in terms of the number of letters in the string that were of the same type as the target letter. For example, the test string lisver would have one letter of the same type as the letter d and five of the same type as m. For each subject, for each of the three types of target letters a RT was computed as a function of the number of letters of the same type in the catch string.

A separate analysis of variance was carried out for each of the three types of test letters. It should be noted that not all of the possible combinations of target letter type and number of similar type catch letters occurred in this experiment. For the ascending letters, RTs were 104 msec shorter in the case in which there were no ascending letters in the catch string relative to the condition in which there were 4 ascenders in the catch string, $F(4,40) = 4.69$, $p < .005$. For the descending target letters, RTs were

144 msec slower when the catch string contained one descending letter than when it contained no descending letters. Although the F-ratio was not statistically significant, $F(1,10) = 2.19$, $p > .10$, all eleven subjects showed this effect, $p < .01$ by a sign test. For x-height letters, RTs were not related to the number of shared letters, $F(4,40) > 1.57$, $p = .2$.

Table 3 summarizes the same kind of analysis using 6 types of letters. Type similarity in this case was defined in terms of the results given by Bouma (1971). The x-height letters are classified into three types. In contrast to the lack of an effect of similarity for the class of x-height letters, RTs within each class showed a consistent increase with increases in the number of similar letters in the catch string. Although not all of the results were significant, this result nonetheless is a strong one, considering that the six letter classes were determined from a study of visual confusions among letters in single-letter visual displays.

Analogous analyses were carried out on the mean RTs for target trials as a function of the number of letters in the test string that were of the same type as the target letter. In contrast to the catch trials, there was not a consistent increase in the RTs with increases in the number of letters of the test string that were of the same type as the target

letter. For the x-height letters, RTs actually decreased 38 msec with increases from 2 to 6 similiar letters, but this effect was not significant, $F(4,40) = 1.86$, $p > .1$. For the ascending letters, RTs did not increase with increases from 1 to 3 similar letters but were significantly slower with 4 letters of the same class than with 1, 2, or 3 letters, $F(3,30) = 9.22$, $p < .001$. Increasing the number of similar descender letters from 1 to 2 actually decreased RT by 21 msec. Table 4 presents the same analysis for the six letter classes. In contrast to the orderly increases on catch trials, there appears to be no systematic effect of letter class similarity on target trials.

Experiment 2

Method

Subjects. Sixteen sixth-grade students, five males and eleven females, participated in individual one-and-a-half hour testing sessions. Two additional students' data were lost due to equipment failures. Chronological ages of the subjects ranged from age 11.0 to age 12.1. Reading comprehension was evaluated by administering the comprehension subtest of the Gates-MacGinitie Reading Test, Survey D, Form 1. Comprehension grade level scores varied from 5.3 to 12+ with a median grade level of 9.5. All subjects participated in response to advertisements in local newspapers and were paid $2 for their participation.

Stimuli and apparatus. The stimuli and apparatus were the same as for the previous experiment with the exception that only List 1 was used.

Procedure. Each subject's session began with administration of the 25 minute written comprehension test. After completing the reading test, the subject was seated before the computer terminal and the task explained. The remainder of the testing session was conducted in the same fashion as the first session of Test Day 1 in the previous experiment. Accordingly, each subject was tested for 50 yes-no trials, 50 practice trials, and 320 trials in the

experiment proper, giving roughly 80 observations per subject at each of the 4 experimental conditions (excluding error trials).

Results

The mean correct RTs and their associated error percentages are presented in Table 5. Although the RTs were about 12 msec. faster for regular than for irregular strings and about 12 msec faster for high than for low positional frequency, an analysis of variance revealed that neither result was significant. The only statistically significant result was the 65 msec mean difference between target trials and the slower catch trials; $F(1,15) = 16.11$, $p < .005$. However, this advantage in RTs on target trials appears to be, at least partially due to higher error rates on those trials. Fourteen of the 16 subjects (significant by a sign test, $p < .02$) were more accurate in responding to catch trials than to target trials. This result suggests that subjects doublechecked their decision when it was negative but not when it was positive. Therefore, subjects would be more accurate on catch trials but also slower than on target trials.

Analyses of similarity between catch string letters and target letters were made as in the previous experiment. Results for the classification into x-height, ascender,

descender classes replicated those found with adult subjects. Catch trial responses were 148 msec slower when the target was an ascender and the string contained three ascenders as compared to no ascenders, $F(3,45) = 8.22$, $p < .001$. Likewise, the "no" decision was slowed by 169 msec when the target was a descender and the display contained a different descender, $F(1,15) = 16.97$, $p < .001$. For x-height letters, however, RT was unrelated to the number of x-height letters in the display, $F(3,45) = .89$. These same trends are also reflected in Bouma's (1971) finer subdivision shown in Table 6.

Similar analyses of the same data for the target trials revealed that the RTs did not increase in any of the nine classes as a function of increasing numbers of letters of the same class as the target (cf. Table 7). These results contrast with those found for catch trials and together the results provide an exact replication of the adult performance in Experiment 1.

Discussion

Experiments 1 and 2 have demonstrated that the target search task was relatively insensitive to the orthographic structure of the test letter strings. Only very small effects of orthographic structure were apparent, whereas target search times were critically dependent on the number

of letters in the test word that belonged to the same letter class as the target letter, that is, on the number of letters which shared a distinctive letter feature with the target letter. RTs on catch trials were slower to the degree that the catch strings had letters of the same class as the target. In terms of our model, this means that the observer was capable of responding at the level of feature detection before recognition of the letters in the test string was complete.

The feature-detection strategy in the target search task disqualifies the task as an appropriate test of the orthographic structure of letter strings. What is required is a task that requires complete resolution of all of the letters of the test string. According to our model, orthographic regularity should influence performance at this stage of information processing. Consider the task in which the test string is presented first followed by presentation of the target letter. In this task, the subject indicates whether or not the target letter was contained in the test string. Here the subject will attempt to resolve the letter string to the deepest level possible. If we present the test display for a short duration followed by a masking stimulus, then we can ask whether orthographic regularity facilitates resolution of the letters in the display.

Method

Subjects. Ten introductory psychology students, five males and five females, participated for an hour a day on two consecutive days and received extra point credit toward their psychology grade. The data from three additional subjects were lost--two for failure to perform the task as instructed and one due to equipment malfunctions.

Apparatus and materials. The stimulus materials and apparatus were the same as in the previous experiments. Because the task was changed from a pre-cued target search to a post-cued target search, the experimental display sequence was reprogrammed as follows. A cardboard mask with a rectangular cut-out window was affixed to the face of the CRT screen. This window defined the area where the displays were presented and served as a fixation box. A trial began with the presentation of the six-letter stimulus string for a brief, controlled duration followed immediately by the masking stimulus, six upper case Xs. The masking stimulus was presented for 250 msec and followed by the target letter which remained in view until the subject responded. The target letter was presented on the same line as the stimulus and mask strings but three character positions to the left of the initial letter position of the stimulus string.

The stimulus string exposure duration was individually determined for each subject during the practice trials.

Because of the 60 Hz refresh rate for the terminal's cathode ray tube, one refresh cycle (16.7 msec) was chosen as the basic time unit. The number of cycles needed to achieve an overall accuracy level of 75% was determined by a computer subroutine PEST (Taylor & Creelman, 1967). Exposure was adjusted only minimally during the experimental trials. An incremental adjustment of one or two cycles was made after each block of trials, if necessary, to maintain accuracy at 75%.[2] The mean exposure duration for the 10 subjects was 8.5 cycles or 142 msec. The range of average exposure durations across subjects varied between 2.1 and 14.8 cycles.

Procedure. The instructions explained the nature of the task to the subjects. They were informed that the exposure duration would be brief and would be adjusted during the session to maintain an accuracy of 75%. It was emphasized that the most accurate judgments possible were desired on every trial. They were also told that half the trials would be target trials and half would be catch trials.

To acquaint the subjects with the response procedure and visual display, each day's session began with 10 trials

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[2] Since each block contained equal numbers of strings in each stimulus category, varying exposure times across blocks was justified.

consisting of only the word "yes" or "no" being presented. The subject merely pressed the correspondingly labelled response button. On the first day the yes-no trials were followed by four 50-trial blocks of practice trials. For the practice trials the stimulus strings were six randomly selected letters. For these trials the initial exposure duration was set at 20 refresh cycles (233 msec) and adjusted, if necessary, every eighth trial. The practice trials were followed by four 80-trial experimental blocks. The procedure for the second day was similar except that only two 50-trial practice blocks were administered and the initial exposure duration for the day was set at the final exposure duration reached the preceding day. On both days the subjects were given short rest breaks between blocks of trials. The subjects were encouraged to rest their eyes and divert their attention from the task during these breaks.

Results

The average percentage of correct responses on the target and catch trials at each of the four experimental conditions are presented in Table 8. Each cell in the table is based on 80 observations for each of the 10 subjects. Regular strings were recognized 4% more accurately than irregular strings, $F(1,9) = 9.67$, $p < .025$. Strings high in positional frequency were recognized 5% more accurately than

strings low in positional frequency, $F(1,9) = 38.61$, $p < .001$. The interaction of regularity and positional frequency was not significant, $F(1,9) = 1$. No other sources of variance were significant.

Performance was analyzed as a function of the similarity of the target letters to the letters in the test items on catch trials. There was no significant effect of the number of similar letters when the classification was made in terms of the three classes of x-height letters, ascenders, and descenders. Table 9 presents the finer-grained analysis when the letters are classified into Bouma's (1971) six groups. The results show no significant decrease in performance with increases in the number of similar letters in any of the six letter classes. The only significant result was the quadratic trend for the letters c, e, and o.

Similar analyses carried out on target trials showed no significant effects of similarity. This null result was obtained for both the classification into x-height, ascenders, and descenders, and into the classification of Bouma's (1971) six letter groups (cf. Table 10).

Discussion

In agreement with our hypothesis, the accuracy task with the target letter presented after the test display was sensitive to the orthographic structure of the test strings.

An orthographically regular string high in positional frequency was recognized 9% better than an irregular low positional frequency string. This result contrasts with the very small effect of these variables in the RT task when the target letter was given before the test string. In contrast to the large effect of similarity between the target letter and letters in the catch strings in the RT task, no consistent effect was observed in the accuracy task. Analogous to the effects of orthographic structure, we believe that the critical variable determining large effects of similarity is the degree to which the subject terminates processing before recognition is complete. If the subject is given the target before the test string and speed of response is stressed, large effects of similarity should be observed. If presentation of the target is delayed until after the test string has been resolved, similarity should not have much of an effect. According to this analysis, tasks that eliminate effects of similarity are more likely to observe positive effects of orthographic structure.

These positive results provide strong evidence against the positional uncertainty hypotheses of Estes (1975). In his view, orthographic structure does not facilitate resolution of the letters in a string but simply reduces uncertainty about their relative spatial positions. In our experiment, identification of the letters was critical to

performance whereas their spatial position was irrelevant to the task. Accordingly, if subjects identified the letters equally for both the regular and irregular strings, as Estes would predict, no differences should have been observed. Given that the positional uncertainty hypothesis also cannot handle the word-letter difference, it does not appear to be an important factor in the perception of letter strings.

In contrast to our expectations, positional frequency had as large an effect as regularity. But upon reviewing the test strings, we noticed that the regular low positional frequency items appeared to be significantly less regular than the regular high positional frequency items. It was much more difficult to find adequate regular strings in the low than in the high positional frequency anagrams. Accordingly, it seemed neccesary to provide an independent assessment of the regularity of the test strings that were employed in these experiments. To this end, college students were asked to rate these strings on orthographic regularity. We suspected that the regular low positional frequency strings would be rated as less regular than the regular strings high in positional frequency.

Experiment 4

Method

Subjects. Fifty-eight subjects were recruited from introductory psychology courses. One subject was eliminated from the analysis because he used the scale backwards.

Stimulus lists. The 320 strings of Lists 1 and 2 were randomized and were typed on 8 pages with 40 items per page. The order of the items on each page was constant across subjects, although each subject received a different random order of the eight pages. Each word was typed in lower case letters with an underlined blank area next to it.

Procedure. Subjects were scheduled in groups of 10. After they were seated and the scaling booklets distributed, the subjects were told the general nature of the experiment and the rating scale to be used. The scale was graphically represented on the blackboard for reference purposes as a line with ten even graduations. The "1" end was marked "least like an English word" and "10" was marked "most like an English word". The subjects were told to read the instructions carefully and then mark a rating for each item. (The instructions are reproduced in the Appendix.) It was emphasized that they should take their time and give thoughtful consideration to each item. Any questions about the procedure were answered. All subjects completed the ratings in 30 to 45 minutes.

Results

Both positional frequency and orthographic regularity had a significant effect on the ratings. Strings high in positional frequency were rated as more like English than strings low in positional frequency (5.06 vs. 4.02), $F(1,56) = 388$, $p < .001$. Regular strings received an average rating of 6.06 which was almost twice the average rating of 3.02 of the irregular strings, $F(1,56) = 337$, $p < .001$. Table 11 shows that the interaction of positional frequency and regularity was also significant, $F(1,56) = 249$ $p < .001$. A specific comparison of the high and low irregular strings showed that the effect of positional frequency was only marginally significant for the irregular strings $F(1,56) = 49$, $p < .001$. The effect of positional frequency was almost entirely due to the regular strings or, to put it another way, the effect of regularity was much larger for high than for low positional frequencies.

Discussion

The rating results confirmed our suspicions that the regular strings were not equally regular for the high and low positional frequencies. Therefore, some or all of the advantage enjoyed by the high positional frequency strings could have been due to regularity. We are currently carrying out a series of experiments with new test strings

that do not confound positional frequency with orthographic regularity.

General discussion. The present research addressed the question of whether or not the target search task is sensitive to the orthographic structure of the test letter strings. Only a small effect of orthographic structure was observed. On the other hand, target search times for catch trials were critically dependent on the number of letters in the test word that belonged to the same letter class as the target letter. RTs on catch trials were slower to the degree that the catch strings contained letters of the same class as the target. In terms of our stage model, this means that the observer was capable of responding at the level of feature detection before recognition of the letters in the test string was complete.

If we assume (1) that a sequence of letters can be processed in parallel, (2) that features of individual letters are extracted continuously, (3) that feature extraction processes operate on all letter positions independently and with unlimited capacity, and (4) comparisons between extracted features in the target letter can occur before perception is complete, then a relatively parsimonious description of the results can be given. Backward masking and partial report experiments (Averbach & Coriell, 1961; Massaro, 1975a; Sperling, 1960) have shown

that the resolution of the visual display occurs gradually over time. In earlier work, however, we have previously conceptualized the perception of the letters as occurring in a two-stage process (Massaro & Klitzke, in press). The overall shape of each letter is assumed to be resolved in the first stage. The second stage of processing follows the first and resolves the details of the letter. In reading, the reader does not have to complete both stages of processing for each letter, but can in many cases identify the letters unambiguously after the first stage of processing. In target search tasks, the subject can select a response after either the first or second stage, depending on the confidence which the subject has in his decision at the end of either stage. The subject maintains a fixed criterion to keep his false alarm rate at a low level. If the information available to the subject at the end of the first stage is sufficient to respond correctly with probability P_c, and $1-P_c < P_f$ where P_f is the maximum false alarm rate which the subject will tolerate, then the subject outputs the response. Otherwise he completes the second stage of processing, and responds after it is complete. This model can be extended to account for the results of the present experiments. It is assumed that letter features are continuously extracted in parallel across all of the letters in the test string. A subject can

initiate a response at any point in this processing sequence. If the subject is given the target letter before the test display presentation, each letter in the string does not have to be completely processed. On catch trials, the subject does not have to recognize all of the letters in the test string, but only has to process enough of each letter to ensure that it is not the same as the target letter. On target trials, the subject must extract enough features from the appropriate letter in order to identify it unambiguously.

The processing time for each letter in the test string on catch trials will be a direct function of the number of features it shares with the target. To the extent the letter does not share features with the target, it can quickly be rejected. Accordingly, test strings that contain nothing but highly dissimilar letters from the target should be responded to very quickly, whereas reaction times should be large for test strings with a large number of similar items to the target letter. In contrast to catch trials, no effects of letter similarity should be observed on target trials. Regardless of the similarity of the nontarget letters in the test string, the target letter must still be resolved sufficiently in order to execute a positive response. Since it is assumed that processing occurs in

parallel, only the time to identify the target letter is critical on positive target trials.

The support for this model of letter recognition comes from the similarity analysis carried out in Experiments 1 and 2. We assume that letters of the same letter class share more features than those that do not. Accordingly, reaction times on catch trials should increase with increases in the number of letters of the same class as the target letter. In agreement with this prediction, average reaction times increased steadily as the number of letters of the same class increased from 0 to 3 (cf. Tables 3 and 6). Further support for the model comes from the negative findings on positive target trials. Reaction times showed no consistent changes as the number of letters of the same class as the target was increased from 1 to 4 (cf. Tables 4 and 7).

Other models of the target search task have been proposed, most notably Gardner's (1973) independent channels confusion model and Estes' (1972) interactive channels model. Both of these models assume that features are extracted in parallel from all letter positions in a visual display. Gardner's model assumes that feature extraction processes are independent at all letter positions for displays in foveal vision, but post-perceptual decision processes permit confusions between the target letter and

confusable noise elements in the display. Although this model could be modified to predict the increase in RT on catch trials with more numerous noise letters similar to the target letter, Gardner assumes that decision processing begins only after perceptual recognition is complete and that decision latency is unaffected by the extent of confusability between target and noise elements. Therefore, the current version of Gardner's model predicts no effect of target letter similarity on RTs to target or catch trials.

Estes' (1972) model assumes that target and nontarget (noise) letters compete for feature extraction resources. Thus, the greater the similarity between target and noise letters the greater the competition. If a target letter is accurately detected "a primary detection response is evoked and processing stops [p. 284]" which results in a rapid yes response. If no primary detection process occurs then processing continues and secondary decision processes must select a yes or no response. This model correctly predicts two features of RT Experiments 1 and 2. Target RTs would be faster than catch RTs, as observed, because they would be the result of the faster primary detection process. Catch trial RTs would increase with increasingly similar noise letters because of the competition during feature extraction. Without further assumptions, however, this model would incorrectly predict that RT to target trials

should also be a function of similarity between the target letter and the noise letters in the display, although the magnitude of this effect need not be as great as on catch trials. Thus, neither Gardner's nor Estes' models adequately predict the results of Experiments 1 and 2 without additional assumptions.

It is necessary to assume that the feature detection strategy that we have proposed is inconsistent with the active utilization of orthographic structure in the target search task. Accordingly, no effects of orthographic regularity will be found in this task if the subject actively utilizes the feature detection strategy. We predict, however, that the utilization of orthographic structure will occur when the reader is required to resolve all of the letters in the test string to the deepest level possible. That is to say, if the subject is no longer able to reject a partially resolved letter as he can in the target search task, then it is to his advantage to utilize what he knows about the structure of letter strings in order to identify all of the letters that make it up. We can encourage the reader to operate along these lines by presenting the test string first followed by a single target letter. Given that the subject does not know the target letter in advance, all of the letters in the test string must be resolved in order to perform the task correctly.

Accordingly, the reader in this task will not be able to utilize the feature detection strategy and should utilize his knowledge of orthographic structure.

The foregoing hypotheses were tested in Experiment 3 in which the test string was followed by the target letter. In agreement with the hypothesis, strings high in orthographic regularity and high in summed positional frequency were recognized better than strings low on these dimensions. Similarly, very little effect of the letter class similarity of the target and the letters in catch strings was observed (cf. Table 9). Following Thompson and Massaro (1973), we assume subjects do not maintain partial information of a briefly presented display, but synthesize the best guess for that display. Accordingly, given the presentation of the target letter after the test string has been processed, subjects either respond positively when they, in fact, perceived the target letter in the test string or negatively when they did not. This interpretation was supported in Thompson and Massaro (1973) and Massaro's (1973) experiments which showed a large effect of similarity when the target alternatives were presented before but not after the test list. The results of the current experiments are also consonant with the theoretical framework and the earlier studies.

Johnston and McClelland (1974) demonstrated the importance of processing strategy on the perception of letter strings. Subjects either were told to attempt to see a whole word or were told the critical letter position in a Reicher-Wheeler task. Subjects were about 7% more accurate with the whole word than with the single letter processing strategy. In terms of our model, subjects utilized the orthographic structure available in the word in the whole word processing strategy but did not take advantage of the letter context when attention was directed to the critical spatial position.

A recent study by Appelman (1976) is also consistent with the present framework. Subjects were presented two words or two nonwords in a same-different task. Subjects were 8% more accurate on word than on nonword trials. In a second experiment, only a single test string was presented with a target letter above or below the critical letter in the test string. Subjects indicated whether the target letter was the same as or different from the critical letter in the test string. The word advantage was eliminated in this task. In terms of our model, subjects processed the letter strings through primary recognition in the first case but not in the second. In the second case, the cue letter would encourage the subject to process only the critical

letter in the test string. Therefore, regularity would not be utilized and no word advantage would be observed.

In summary, our results and analyses of the target-search task lead to the conclusion that target-search is not an appropriate paradigm for studying the role of orthographic structure in reading. The feature detection strategy appears to be inconsistent with the active utilization of orthographic structure in processing letter strings.

Table 1

Letter Strings of Similar Positional Frequency that Are Either Orthographically Regular or Irregular

Regular	Irregular
girbed (1721)	grbied (1690)
pirons (1409)	sopinr (1409)
filtes (1750)	flties (1775)
citred (1861)	tcried (1886)
hougen (1399)	nhoueg (1409)

*The numbers in parenthesis give the summed positional frequency for letter strings.

Table 2

Mean RT (msec) for target and catch trials in Experiment 1 as a function of positional frequency and orthographic regularity. Associated error percentages are shown in parentheses.

Orthographic Regularity	Target		Catch	
	Positional Frequency		Positional Frequency	
	High	Low	High	Low
Regular	622 (2.5)	639 (3.0)	696 (2.0)	713 (1.8)
Irregular	631 (2.5)	639 (4.0)	706 (1.8)	729 (2.0)

Table 3

Mean RTs for catch trials in Experiment 1 as a function of the number of letters in the string that belonged to the same letter class as the target letter.

Letter Class	Number of letters of same class				
	0	1	2	3	F ratio
m, n, r, u, v, w	704	720	744	759	F(3,30)= 3.01*
a, s, x, z	732	749	777		F(2,20)= .37
c, e, o	725	729	746	780	F(3,30)= 1.19
b, d, h, k	674	780			F(1,10)= 32.79**
f, i, j, l, t	628	671	709	755	F(3,30)= 24.04**
g, p, q, y	667	808			F(1,10)= 2.19***
Average	688	742	744	765	

*=$p < .05$

**=$p < .001$

***=$p < .001$ by a sign test

Table 4

Mean RTs for target trials in Experiment 1 as a function of the number of letters in the test string that belonged to the same letter class as the target letter.

Letter Class	Number of letters of same class				
	1	2	3	4	F ratio
m, n, r, u, v, w	674	666	663	630	F(3,30)= 3.68*
a, s, x, z	650	625	608		F(2,20)= 2.14
c, e, o	623	592	610	590	F(3,30)= 2.11
b, d, h, k	649	682	856		F(2,20)= 11.90**
f, i, j, l, t	621	607	599	692	F(3,30)= 2.48
g, p, q, y	613	592			F(1,10)= .53
Average	638	627	667	637	

* $p < .025$

** $p < .001$

Table 5

Mean RTs (msec) for target and catch trials in Experiment 2 as a function of positional frequency and orthographic regularity. Associated error percentages are shown in parentheses.

Orthographic Regularity	Target		Catch	
	Positional Frequency		Positional Frequency	
	High	Low	High	Low
Regular	850 (8.4)	848 (7.0)	907 (4.8)	934 (3.6)
Irregular	858 (7.7)	878 (6.9)	922 (4.1)	929 (2.7)

Table 6

Mean RTs for catch trials in Experiment 2 as a function of the number of letters in the test string that belonged to the same letter class as the target letter.

Letter Class	Number of letters of the same class				
	0	1	2	3	F ratio
m, n, r, u, v, w	951	944	957	1080	F(3,43)= 2.49*
a, s, x, z	930	930			F(1,15)= .00
c, e, o	908	922	972		F(2,27)= 1.80
b, d, h, k	847	995			F(1,15)= 32.41***
f, i, j, l, t	844	900	988		F(2,15)= 10.70**
g, p, q, y	829	984			F(1,15)= 16.94***
Average	885	946	972	1080	

* .05 < p < .10

** p < .005

*** p < .001

Table 7

Mean RTs for target trials in Experiment 2 as a function of the number of letters in the test string in the same letter class as the target letter.

Letter Class	Number of letters of same class				
	1	2	3	4	F ratio
m, n, r, u, v, w	877	855	855	839	F(3,45)= .40
a, s, x, z	874	858			F(1,15)= .20
c, e, o	854	830	887		F(2,29)= .87
b, d, h, k	923	916	885		F(2,28)= .24
f, i, j, l, t	808	818		863	F(1,15)= 1.28
g, p, q, y	869	842			F(1,14)= .75
Average	868	853	876	851	

Table 8

Average percentage of correct responses for target and catch trials in Experiment 3 as a function of positional frequency and orthographic regularity.

Orthographic	Target		Catch	
Regularity	Positional Frequency		Positional Frequency	
	High	Low	High	Low
Regular	86.0	78.9	85.5	81.5
Irregular	80.2	75.2	83.0	78.2

Table 9

Mean percentage correct for catch trials in Experiment 3 as a function of the number of letters in the test string that were of the same letter class as the target letters.

Letter Class	Number of letters of the same class				
	0	1	2	3	F ratio
m, n, r, u, v, w	76.8	75.6	80.3	78.7	F(3,27)= .25
a, s, x, z	82.5	77.6	73.3		F(2,18)= .74
c, e, o	70.3	87.7	85.9	75.7	F(3,27)= 3.41*
b, d, h, k	84.8	82.1			F(1,9) = .38
f, i, j, l, t	86.5	87.9	83.4	77.7	F(3,27)= .81
g, p, q, y	92.5	86.1			F(1,9) = 1.91
Average	82.2	82.8	80.7	77.4	

* $p < .05$

Table 10

Mean percentage correct for target trials in Experiment 3 as a function of the number of letters in the test string that were of the same letter class as the target letter.

Letter Class	Number of letters of the same class				
	1	2	3	4	F ratio
m, n, r, u, v, w	84.1	77.7	80.5	83.4	F(3,27)= 1.36
a, s, x, z	74.3	77.0	83.5		F(2,18)= .96
c, e, o	88.9	79.6	83.1		F(2,18)= 2.37
b, d, h, k	75.1	80.3			F(1,9) = .59
f, i, j, l, t	71.1	80.2	78.0		F(2,18)= 2.32
g, p, q, y	79.2				
Average	78.8	79.2	81.4	83.4	

Table 11

Average ratings in Experiment 4 as a function of summed positional frequency and orthographic regularity.

Positional Frequency	Regularity		
	Regular	Irregular	Average
High	6.82	3.30	5.06
Low	5.20	2.91	4.05
Average	6.01	3.11	

Appendix

The words, the four permutations used in the experiments, and the summed positional frequency of each for List 1

Words		High-Regular		High-Irregular		Low-Regular		Low-Irregular	
MODERN	1010	REMOND	1600	RMNOED	1651	ENDROM	426	RDENMO	431
MINUTE	1167	MUINET	1446	MNTIEU	1406	ITENUM	383	INEMTU	384
ITSELF	751	SIFLET	1664	TLFIES	1674	ESTFIL	429	EFLSTI	428
MASTER	1727	MATSER	1671	MRATES	1693	ESTRAM	465	EMTRSA	471
ISLAND	1000	SINALD	1505	LANISD	1490	INDSAL	372	INLSDA	372
HAPPEN	1420	PHANEP	1325	PAHPNE	1271	ENPAPH	375	EHPNPA	393
GROUND	1264	GONURD	1278	RUOGND	1266	ODGRUN	342	ONDRGU	346
GOLDEN	1417	GENOLD	1530	OLNGED	1539	ENGDOL	458	ELDNGO	459
GARDEN	1568	NAGRED	1708	ARNGED	1721	EDGRAN	416	EDNRGA	402
FRIEND	1324	FIRDEN	1546	IRFNED	1560	ENDRIF	372	EFNRDI	371
FINGER	1530	FIRGEN	1544	FRNIEG	1587	EFGRIN	428	INERFG	442
FARMER	1719	RAMFER	1573	AFMRER	1372	ERMRAF	538	ERARFM	533
DURING	1164	RIGUND	1293	UIRGND	1284	IDGRUN	328	UNDRGI	324
DOUBLE	1171	BOUDEL	1448	LBUOED	1599	ODELUB	286	EBDLUO	271
DIRECT	1073	TECIRD	1609	TERICD	1615	EDTRIC	447	ETRCDI	447
BROKEN	1467	RONKEB	1372	BEOKNR	1364	ENBROK	391	ERKNBO	392
BELONG	1356	GOLBEN	1377	BENOLG	1378	ENGLOB	415	ONELGB	414
BEHIND	1657	HIBNED	1655	HNBIED	1654	ENDHIB	332	INEDHB	325
AROUND	1411	NAROUD	1313	UOARND	1304	ODURAN	441	NDORAU	441
AMOUNT	1048	MANOUT	1054	UAOTNM	1061	OTUNAM	440	NMUTAO	440
ALMOST	955	SAMOLT	1480	MAOTLS	1479	OTSLAM	454	OSLTMA	447
ACTION	988	ACOINT	1223	COAITN	1223	INCATO	455	NTIACO	445
YELLOW	825	LEWOLY	1278	OLWLEY	1215	ELYLOW	470	EYLWOL	455
WONDER	1526	WRONED	1719	WNROED	1737	EDWRON	457	EDWNRO	444
WINTER	1584	WERINT	1513	WTNIER	1525	ETWRIN	476	ETWNRI	503
TRAVEL	1321	VARTLE	1466	AVRLET	1475	TRELVA	528	TLERAV	516
TOWARD	1205	WATORD	1447	WAOTRD	1458	OTDRAW	359	RTDWAO	378
STREAM	918	TASMER	1608	MRTAES	1603	ESTRAM	465	MTERSA	496
SPREAD	1287	SARDEP	1687	PRSAED	1692	EDRSAP	417	ESRDPA	429
SINGLE	1413	NIGLES	1491	SGNIEL	1528	ENGSIL	398	NGELSI	379
SIMPLE	1411	LIMPES	1643	PMLIES	1649	EMPSIL	342	ESPLMI	282
SILVER	1657	LISVER	1492	SERILV	1538	EVSRIL	430	RSELIV	444
SECOND	1725	SOCEND	1621	CDNOES	1559	ENDSOC	395	ESCNDO	389
REMAIN	1013	NAIMER	1528	AEMINR	1526	INERAM	390	RMENAI	461
RESULT	1357	SURTEL	1651	LRTUES	1689	ESTRUL	464	ELSRTU	519
REASON	1081	SARONE	1712	SRAOEN	1677	OSERAN	458	ESNROA	445
PRINCE	1008	CIPNER	1531	PCNIER	1583	ENCRIP	426	ENRCPI	417
PERIOD	1679	PODIER	1735	PEOIRD	1714	EDIROP	413	ERDPIO	433
NUMBER	1310	MURBEN	1390	BNRUEM	1407	EMBRUN	364	RNEMBU	385
BRIDGE	1001	RIBGED	1660	BERIGD	1678	EGDRIB	285	IGERDB	270

Appendix (continued)
The words, the four permutations used in the experiments, and the summed positional frequency of each for List 1

Words		High-Regular		High-Irregular		Low-Regular		Low-Irregular	
ACCEPT	810	PACCET	1580	CCAPET	1438	ECTCAP	408	CTECPA	396
SPIRIT	818	PIRIST	1256	PITISR	1208	ISPRIT	475	TPSRII	455
REPORT	1217	TROPER	1508	TPROER	1531	TREROP	605	ERPTRO	658
REALLY	1348	LERALY	1390	LRLAEY	1457	LYERAL	506	YLELRA	521
OFFICE	902	COFIFE	1244	FCFIEO	1299	EFICOF	365	EFCFOI	332
RETURN	1247	RUTNER	1538	TNRUER	1546	ERTRUN	657	RRENTU	649
REFUSE	1293	SUFEER	1662	SRFUEE	1782	ESERUF	312	ESREFU	548
REGARD	1342	DRAGER	1439	AERRGD	1468	EDGRAR	497	RDGERA	607
SEASON	1227	ASONES	1577	SEOANS	1597	ESOSAN	564	NSSEOA	546
SCHOOL	772	SOLOCH	1067	HCOOLS	1137	OSCHOL	442	LSOCHO	437
SISTER	1780	SIRSET	1772	SRTIES	1967	TRESSI	560	ESRTSI	620
STREET	1754	RETTES	1986	SRTTEE	1917	ETERTS	771	RTESTE	882
SUDDEN	1409	DESUND	1498	DSNUED	1568	ESDDUN	371	DNESDU	373
SUMMER	1555	MERUMS	1303	SRMMEU	1355	EMSRUM	339	RSEMMU	357
VALLEY	1541	VALELY	1215	LLVAEY	1322	VYELAL	398	YLELAV	399
ACROSS	1093	CASORS	1359	SAOCRS	1374	OSSCAR	492	OCSSRA	485
AFRAID	1067	AFRIAD	1265	ARAIFD	1282	IDARAF	414	RDFAAI	418
AFFAIR	690	FARAIF	922	AFAIFR	927	ARIFFA	480	RFAAFI	470
ANIMAL	590	LAMIAN	1148	AAIMLN	1144	INALMA	452	ILNMAA	427
APPEAR	769	PAPARE	1225	AAPPRE	1238	EPARAP	457	PPERAA	453
ARRIVE	1275	VAIRER	1516	RRAIEV	1504	EVIRAR	567	RREAIV	569
BATTLE	1592	TABTEL	1518	BEATLT	1502	ETTLAB	522	ETLATB	516
BECAME	1244	CEABEM	1574	BCMAEE	1572	EBECAM	291	EBEAMC	332
BECOME	1335	BOCEEM	1560	MBCOEE	1534	EBECOM	338	EMEOBC	396
BEFORE	1458	BOREEF	1676	BRFOEE	1713	EBEFOR	516	OREFFB	519
BESIDE	1456	BIDEES	1732	BSIEED	1701	EDESIB	316	ISEEDB	409
BETTER	1931	BETRET	1830	BRTTEE	1818	ERBETT	812	ETTRBE	810
CANNOT	1148	COTANN	1166	AOCTNN	1192	ONTCAN	536	NCNTAO	534
CHANCE	1072	CACHEN	1569	CCAHEN	1340	ECHCAN	385	ENHCCA	280
DECIDE	1344	CIEDED	1756	CDEIED	1743	EDEDIC	342	EDEEDC	415
DEGREE	1730	GEDEER	1663	GREEED	1665	EREDGE	855	EEERDG	865
DEMAND	1451	NAMDED	1794	ANMDED	1639	EDDMAN	393	EDNADM	393
DESIRE	1495	REISED	1912	SRDIEE	1881	EDESIR	530	ISEEDR	623
DOLLAR	929	LORALD	1513	AORLLD	1564	OLDRAL	449	OLLRDA	449
EFFORT	778	FOFRET	1543	FFROET	1523	ETORFF	464	EFRFTO	464
EITHER	1500	HEITER	1752	HTRIEE	1789	HTEERI	666	EHERIT	666
ESCAPE	696	CASEEP	1596	SPCAEE	1627	ECESAP	364	ASEEPC	555
FELLOW	959	WOLLEF	1363	LLFOEW	1283	ELLFOW	476	LWEFOL	461
FUTURE	1192	RUFUET	1466	FRUUET	1472	UFERUT	472	ERTFUU	438
HEAVEN	1597	HAVEEN	1555	VHANEE	1554	EVEHAN	441	ENEAVH	429

APPENDIX (continued)

The instructions used for the scaling task in Experiment 3

On the pages which follow are letter strings made up to look like English words. None of the strings, however, is an English word. Your task is to rate each one on a scale of 1 to 20 according to how much it looks like a real English word. Strings which are extremely close should be given high ratings, while strings which are not very close should be given low ratings. Since no real words are included, the highest possible rating (10) should be given to strings which you feel are most like English words. Similarly, a rating of 1 should be given to the strings which are least like English words. The strings have been selected to represent all possible levels of similarity to English, with roughly equal numbers at each level.

Skim over the strings on the first page before you begin rating so you have an idea of their range of variation. There are 320 strings in all, divided randomly across 8 pages, so each page should have roughly the same variation as any other. You should work at a fairly quick and even pace, although there is no time limit.

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